Work (W)

Work is defined as a force acting upon an object to cause a displacement

It is expressed as the product of force and displacement in the direction of force.

$W=F \times s$

Here W= work done on an object

F = Force on the object

s = Displacement of the object

The unit of Work is Newton metre (Nm) or joule (J).

1 Joule is defined as the amount of work done by force of 1 N when displacement is 1 m.

$1j=10^7$erg

Examples of Scientific Work Done are:

- Moving a chair from one location to another
- Lifting a book from the shelf and placing it on a table
- Pushing a pebble lying on the ground.

Sign Conventions for Work Done

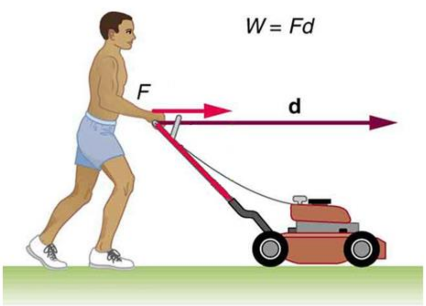
- when both the force and the displacement are in the same direction, positive work is done.

  $W = F \times s$
- when force acts in a direction opposite to the direction of displacement, the work done is negative.

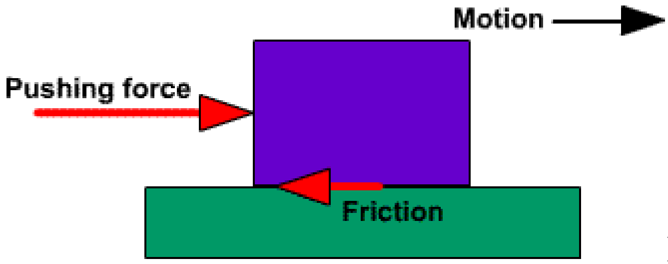
  $W= - F \times s$

  Angle between force and displacement is 180^o.
- If force and displacement are inclined at an angle less than 180^o, then work done is given as:

  $W= Fs \cos\theta$
- If force and displacement act at an angle of 90° then work done is zero.



POSITIVE WORK



NEGATIVE WORK

ZERO WORK

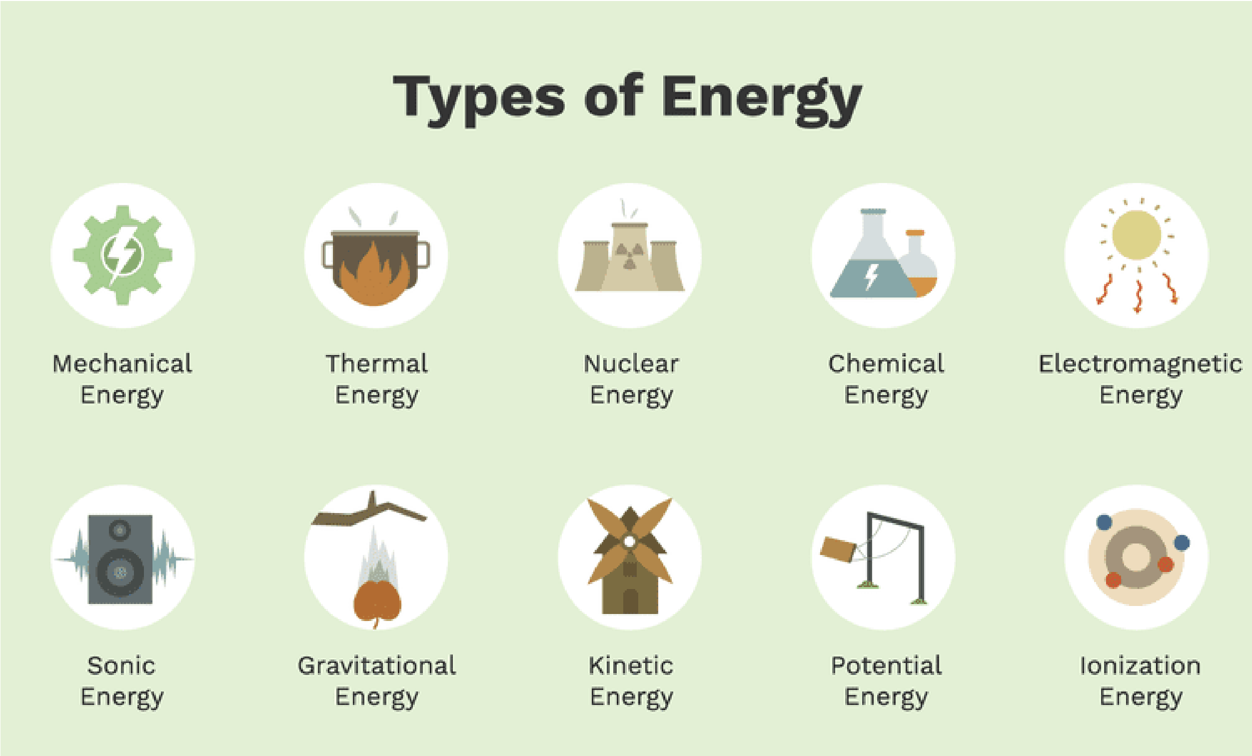
Necessary Conditions for Work to be done

Two conditions need to be satisfied for work to be done:

- Force should act on the object.
- Object must be displaced.

Energy

Any object that is capable of doing work processes some energy. The object can gain or lose energy depending upon the work done. If an object does some work it loses its energy and if some work is done on an object it gains energy.



Unit of energy = Joules

1KJ = 1000 J

Kinetic Energy

- It is the energy possessed by a body due to its motion. Kinetic energy of an object increases with its speed.
- Kinetic energy of body moving with a certain velocity = work done on it to make it acquire that velocity

  Derivation

  Let an object of mass m, starts from rest and attains a uniform velocity v, after a force F is applied on it. Let during this period the object be displaced by distance s.

Thus, Work done on object, $W = F \times s$ ....(i)

Let the acceleration produced after applying force on object be a.

So, using third equation of motion, we have:

$$v^2 - u^2 = 2as$$

$$\Rightarrow \quad s = \frac{v^2 - u^2}{2a} \quad \text{....(ii)}$$

Also, Force is given as, $F = ma$ ....(iii)

Substituting F and s fromequations (ii) and (iii) in equation (i), we get:

$$W = F \times s$$

$$\Rightarrow \quad W = ma \times \frac{v^2 - u^2}{2a}$$

$$\Rightarrow \quad W = \frac{1}{2}mv^2 \left[\text{As, initial velocity, } u = 0\right]$$

But, work done on object = Change in kinetic energy of object

$$\therefore \quad E_k = \frac{1}{2}mv^2$$

Potential Energy

The energy possessed by a body due to its position or shape is called its potential energy.
For Example:

- Water stored in a dam has large amount of potential energy due to its height above the ground.
- A stretched rubber band possesses potential energy due to its distorted shape.

Types of Potential Energy

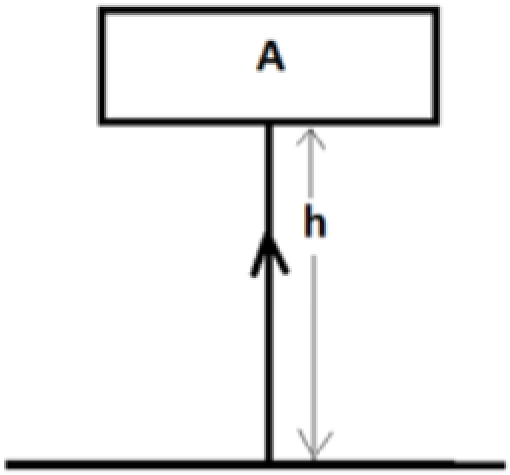
On the basis of position and change in shape of object, potential energy is of two type:

1. Gravitational Potential Energy:
It is the energy possessed by a body due to its position above the ground.

2. Elastic Potential Energy:
It is the energy possessed by a body due to its change in shape.

EXPRESSION FOR POTENTIAL ENERGY

Consider the example given below



An object ‘A’ having mass ‘m’ is raised by height ‘h’ above the ground. Let us calculate the potential energy of object A at height ‘h’:

We know that,

W = F * d = F * h (height)

And F = m * g (because the force is applied against gravity)

So, W = m * g * h

Hence potential energy of object A, Ep = m * g * h

Gravitational potential energy does not get affected due to the path taken by the object to reach a certain height.

Other forms of Energies:

- Mechanical Energy – It is the sum of kinetic and potential energy of an object. Therefore, it is the energy obtained by an object due to motion or by the virtue of its location. Example, a bicycle climbing a hill possesses kinetic energy as well as potential energy.
- Heat Energy – It is the energy obtained by an object due to its temperature. It is also called Thermal Energy. Example, energy possessed by a hot cup.
- Chemical Energy – It is the energy accumulated in the bonds of chemical compounds. Chemical energy is released at the time of chemical reactions. Example, energy possessed by natural gas and biomass.
- Electrical Energy – It is kind of kinetic energy caused due to the motion of electrons. It depends upon the speed of electrons. As the speed increases so does the electrical energy. Example, electricity produced by a battery, lightning at thunderstorms
- Light Energy – It is the energy due to light or electromagnetic waves. It is also called as Radiant Energy or Electromagnetic Energy. Example, energy from the sun

- Nuclear Energy – It is the energy present in the nucleus of an atom. Nuclear energy releases when the nucleus combines or separate. Therefore, we can say that every atom in this universe comprises of nucleus energy. Example, uranium is a radioactive metal capable of producing nuclear energy in nuclear power plants
- Sonic Energy – It is the energy produced by a substance as it vibrates. This energy flows through the substance in the form of sound waves. Example, music instruments produce sound energy
- Ionization Energy – It is the energy that binds electrons with its nucleus. It is thus the amount of energy required to remove one electron completely from its atom (called First Ionization Energy). Subsequently, the ionization energy increases as we remove the second electron from the atom (called Second Ionization Energy).

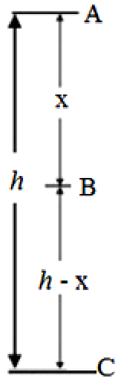
One form of energy can be transformed into other forms of energy.

Law of Conservation of Energy

It states that energy can neither be created nor destroyed, but it can be transformed from one form to another.

The total energy before and after the transformation remains the same.

Proof of Law of Conservation of Energy
Let a body of mass m falls from a point A, which is at a height h from the ground as shown in the following figure:



At point A,
Kinetic energy $E_k = 0$
Potential energy $E_p = mgh$
Total energy, $E_A = E_p + E_k$
$\Rightarrow \quad E_A = mgh + 0$
$\Rightarrow \quad E_A = mgh$
During the fall, after moving a distance x from A, the body has reached at B.

At point B,
Let the velocity at this point be v.

We know, $v^2 = u^2 + 2as$
$\Longrightarrow \quad v^2 = 0 + 2ax = 2ax$ [As, velocity at A, u = 0]
Also, Kinetic energy, $E_k = 1/2\ mv^2$
$\Longrightarrow \quad E_k = 1/2\ m \times 2gx$
$\Longrightarrow \quad E_k = mgx$
Potential energy, $E_p = mg\ (h - x)$
So, total energy, $E_B = E_p + E_k$
$\Longrightarrow \quad E_B = mg\ (h - x) + mgx$
$\Longrightarrow \quad E_B = mgh - mgx + mgx$
$\Longrightarrow \quad E_B = mgh$
At the end the body reaches the position C on ground.

At point C,
Potential energy, $E_p = 0$
Velocity of the body is zero here.

So, $v^2 = u^2 + 2as$
$\Longrightarrow \quad v^2 = 0 + 2gh = 2gh$
Kinetic energy, $E_k = 1/2\ mv^2$
$\Longrightarrow \quad E_k = 1/2 \text{ x } m \text{ x } 2gh = mgh$
Total energy at C

$E_C = E_p + E_k$
$E_C = 0 + mgh$
$E_C = mgh$

Hence, energy at all points remains same.

Power
The time rate of doing work is defined as power (P).

Power= work/time

Unit of power

- SI unit of Power is Joule per second or Js1.
- 1 watt is the power when 1J of work is done in 1s.
- The bigger unit of power is Kilowatt and represented by kW.

1kW = 1000W

- Some another units to measure power are:

1 Megawatt = 10^6 watt

1 horse power = 746 watt

Commercial unit of energy

- Commercial unit of energy is kilo watt hour (kWh)
- The unit kilowatt-hour means one kilowatt of power supplied for one hour.

1 kWh = 1 kW x 1 h

= 1000 W x 60 x 60 s

= 1000 Js^{-1} x 3600 s

= 3.6 x 10^6 J

1 unit = 1 kilowatt hour = 3.6x10^6 J.

SOLVED NUMERICALS

Question :

A force of 7 N acts on an object. The displacement is, say 8 m, in the direction of the force (Fig. 11.3). Let us take it that the force acts on the object through the displacement. What is the work done in this case?

Answer:

When a force F acts on an object to displace it through a distance S in its direction, then the work done W on the body by the force is given by:

Work done = Force × Displacement

W = F × S

Where,

F = 7 N

S = 8 m

Therefore, work done, W = 7 × 8

= 56 Nm

= 56 J

Question

A pair of bullocks exerts a force of 140 N on a plough. The field being ploughed is 15 m long. How much work is done in ploughing the length of the field?

Answer:

Work done by the bullocks is given by the expression:

Work done = Force × Displacement

W = F × d

Where,

Applied force, F = 140 N

Displacement, d = 15 m

W = 140 × 15 = 2100 J

Hence, 2100 J of work is done in ploughing the length of the field.

Question

The kinetic energy of an object of mass, m moving with a velocity of 5 m s−1 is 25 J. What will be its kinetic energy when its velocity is doubled? What will be its kinetic energy when its velocity is increased three times?

Answer:

Expression for kinetic energy is

m = Mass of the object

v = Velocity of the object = 5 m s−1

Given that kinetic energy, = 25 J

(i) If the velocity of an object is doubled, then v = 5 × 2 = 10 m s−1.

Therefore, its kinetic energy becomes 4 times its original value, because it is proportional to the square of the velocity. Hence, kinetic energy = 25 × 4 = 100 J.

(ii) If velocity is increased three times, then its kinetic energy becomes 9 times its original value, because it is proportional to the square of the velocity. Hence, kinetic energy = 25 × 9 = 225 J.

Question

A lamp consumes 1000 J of electrical energy in 10 s. What is its power?

Answer:

Power is given by the expression,

Work done = Energy consumed by the lamp = 1000 J

Time = 10 s

= 100 W

Question

Define average power.

Answer:

A body can do different amount of work in different time intervals. Hence, it is better to define average power. Average power is obtained by dividing the total amount of work done in the total time taken to do this work.

Question

An object thrown at a certain angle to the ground moves in a curved path and falls back to the ground. The initial and the final points of the path of the object lie on the same horizontal line. What is the work done by the force of gravity on the object?

Answer:

Work done by the force of gravity on an object depends only on vertical displacement. Vertical displacement is given by the difference in the initial and final positions/heights of the object, which is zero.

Work done by gravity is given by the expression,

W = mgh

Where,

h = Vertical displacement = 0

W = mg × 0 = 0 J

Therefore, the work done by gravity on the given object is zero joule.

Question

Certain force acting on a 20 kg mass changes its velocity from 5 m s−1 to 2 m s−1. Calculate the work done by the force.

Answer:

Kinetic energy is given by the expression,

Where,

= Kinetic energy of the object moving with a velocity, v

m = Mass of the object

(i) Kinetic energy when the object was moving with a velocity 5 m s−1

(ii) Kinetic energy when the object was moving with a velocity 2 m s−1

Work done by force is equal to the change in kinetic energy.

Therefore, work done by force =

= 40 − 250 = −210 J

The negative sign indicates that the force is acting in the direction opposite to the motion of the object.

Question

A mass of 10 kg is at a point A on a table. It is moved to a point B. If the line joining A and B is horizontal, what is the work done on the object by the gravitational force?

Explain your answer.

Answer:

Work done by gravity depends only on the vertical displacement of the body. It does not depend upon the path of the body. Therefore, work done by gravity is given by the expression,

W = mgh

Where,

Vertical displacement, h = 0

∴W = mg × 0 = 0

Hence, the work done by gravity on the body is zero.

Question

The potential energy of a freely falling object decreases progressively. Does this violate the law of conservation of energy? Why?

Answer:

No. The process does not violate the law of conservation of energy. This is because when the body falls from a height, then its potential energy changes into kinetic energy progressively. A decrease in the potential energy is equal to an increase in the kinetic energy of the body. During the process, total mechanical energy of the body remains conserved. Therefore, the law of conservation of energy is not violated.

Question

An object of mass 40 kg is raised to a height of 5 m above the ground. What is its potential energy? If the object is allowed to fall, find its kinetic energy when it is half-way down.

Answer:

Gravitational potential energy is given by the expression,

W = mgh

Where,

h = Vertical displacement = 5 m

m = Mass of the object = 40 kg

g = Acceleration due to gravity = 9.8 m s^{-2}

∴ W = 40 × 5 × 9.8 = 1960 J.

At half-way down, the potential energy of the object will be = 980 J.

At this point, the object has an equal amount of potential and kinetic energy. This is due to the law of conservation of energy. Hence, half-way down, the kinetic energy of the object will be 980 J.

Question

An electric heater is rated 1500 W. How much energy does it use in 10 hours?

Answer:

Energy consumed by an electric heater can be obtained with the help of the expression,

Where,

Power rating of the heater, P = 1500 W = 1.5 kW

Time for which the heater has operated, T = 10 h

Work done = Energy consumed by the heater

Therefore, energy consumed = Power × Time

= 1.5 × 10 = 15 kWh

Hence, the energy consumed by the heater in 10 h is 15 kWh.

Question

Find the energy in kW h consumed in 10 hours by four devices of power 500 W each.

Answer:

Energy consumed by an electric device can be obtained with the help of the expression for power,

Where,

Power rating of the device, P = 500 W = 0.50 kW

Time for which the device runs, T = 10 h

Work done = Energy consumed by the device

Therefore, energy consumed = Power × Time

= 0.50 × 10 = 5 kWh

Hence, the energy consumed by four equal rating devices in 10 h will be 4 × 5 kWh = 20 kWh = 20 Units.